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CONTROLLING FIRE GROWTH IN ELECTRICAL CABLE COMPARTMENT BY REDUCING OXYGEN CONCENTRATION AT HORIZONTAL ORIENTATION

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ABSTRACT

A series of laboratory tests for electrical fires have been carried out by researchers, and some of the results have confirmed and been adopted as standard. However, the studies focus on electrical fires in PVC insulation material and the melting temperature and toxicity of PVC insulation. By focusing on heat conductors, the growth and spread of a fire can be eliminated by reducing the oxygen concentration, especially inside the compartment. Electrical fires are the most common cause of compartment and building fires both internationally and nationally, according to statistics (Liu & Benichou, 2008). Whatever the triggers are inside the electrical compartment on the connection, termination, or cable, this research looks into electrical fires caused by 1.0–1.5 mmsq electrical cables. Electrical fires in cables are normally started by increasing temperatures inside the cable conductor. By controlling and adjusting the oxygen concentration inside the electrical compartment under atmospheric concentration, one can hamper a fire's start, trigger, propagation, and growth. This study investigates the effectiveness of oxygen concentration on preventing the growth of fires triggered by electrical cabling. A series of studies were created in laboratory scale in a horizontal compartment with oxygen levels of 19%, 17%, and 15%. This paper presents the results of this experiment by studying the effects of reducing oxygen concentration on the fire growth in cable network in a horizontal orientation. The results show that controlling the oxygen concentration at levels lower than atmospheric concentrations can effectively reduce the propensity for cable ignition and lower the fire propagation rate.

Keywords: Cable fire; Electrical fire; Electrical fire prevention; Oxygen controlling; Oxygen reduction

1. INTRODUCTION

This study was inspired by cable test standards such as BS-4066, BS-6387, CEI-20-35/1 (EN-50265), DIN-4102 Part 12, IEC 60332-1, IEC 60332-2, and Singapore Std 299 Part 1. Some of the UL standard test procedures for electrical cable use references such as UL-44, UL-62, UL-83, and UL-1581. For cable fire propagation in vertical and horizontal orientations and cables, the study looked at UL-1666, UL-1685, UL-2196, UL-910, and NFPA-262. ASTM also published standards for electrical tests such as ASTM-D 618, ASTM D-789, ASTM E-162, ASTM D-5025, ASTM D-5207, ASTM D-635, ASTM D-3801, ASTM D-4804,

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ASTM D-5048, and ASTM D-4986 (Liu & Benichou, 2008); these all focus on the growth, spread, and propagation of fires within cable insulation.

Previous researchers focused on cable fires using pilot fires and were concerned about the growth, spread, and propagation of fire in cable insulation; some of these are Barnes et al. (1996) who followed the glowing wire test based on IEC 60695-2-1 and IEC 60695-2-2; Meyer et al. (1996) executed cable fires using random testing without following test standards. By using a cone calorimeter, Nakagawa (1998) identified the ignition temperature of cable insulation. Anderson dan Van Hess (2000) identified the fluctuation of heat by electrical short circuit also using a cone calorimeter. Betrand et al. (2001) tested electrical cables above cable trays inside the compartment and observed the heat fluctuation during electrical short-circuits. Hoffmann et al's study identified cable temperatures by radiant heat. Hagimoto et al. (2003) identified the temperature during electrical arching between two cables within a certain distance. Hasegawa et al. (1986) used the furnace to identify electrical cable ignition temperatures. The focus of these studies is on cable insulation, as well.

Whether the electrical current flows inside the electrical conductor horizontally or vertically has no impact. Each power cable has a resistance to the flow of electric current, depending on the cross-sectional area in the electrical cord; this is known as c*apability* flow conductivity (CFC) (Brabauskas, 2003). Increasing the temperature inside the electrical conductor will impact the material's electrical resistance. The electrical current flows that are inside the cable conductor will decrease gradually because of electrical resistance; this will increase the electrical current inside of the electrical conductor, and it occurs repeatedly. The relationship between the electrical current and temperature can be expressed in the following equations:

$$V = I.R \quad \text{and} \quad R = \rho \frac{l}{A} \tag{1}$$

$$R_t = R_0 \cdot [1 + \alpha(T_t - T_0)] \tag{2}$$

where;

V : Electrical voltage (volt)
T_t : Final temperature (^oC)
I : Electrical current (ampere)
T_0 : Initial temperature (^oC)
R : Electrical resistance (ohm)
R_0 : Initial resistance (ohm) 5t v
α : Resistivity coefficient (1/K or 1/°C)
R_t : Resistance at temperature (^oC)

This study uses two main research methods: keeping the electrical current constant and letting the electrical fluctuate. This research studies only the constant electrical current at and horizontal orientation.

Burdening the electrical cable over its loading capacity from electrical overload or an electrical short circuit will impact the heat inside the electrical conductor; if it is not controlled, it will lead to a fire. The process of overheating the electrical cables begins with the heating of cables inside the cable core; this melts the PVC-based insulation material. This introduces oxygen and creates a fire (FEMA Installation, 2015; Mc Grattan et al., 2010; Hasegawa et al., 1986). Electrical short circuits may cause fires because of the generation of a plasma arc. Electrical short circuits cause unlimited electrical currents, which impact the heat in an electrical system and assume make them 8–10 times higher than the nominal conductor current (*In: nominal current*).

In an electrical system is protected with miniature circuit breakers (MCBs) and earth leakage circuit breakers (ELCBs); they limit the overheating inside an electrical conductor and can prevent potential electrical fires. Problems occur if the electrical current and electrical protection devices are not properly designed or the electrical current flowing inside the electrical conductor is not properly designed. On the other side, fires in the cable system begin with a gradual increase of the internal temperature; in electrical short circuits, the current increases instantly and the heat is generated quickly. Controlling the oxygen concentration inside of the compartment is believed to be one method of fire protection and prevention. Controlling the oxygen concentration can affect the propagation of fire on multiplex woods material (Brabauskas, 2003). The effectiveness of the oxygen concentration and fire reduction on electrical cables in horizontal and vertical orientations still needs to be studied.

Oxygen concentrations are closely related to human safety. Normal oxygen concentration is around 20.9%. Reducing the oxygen concentration to 15%–19% has no effect to human life, but further reduction to 12% may cause tiredness, 10% may cause dizziness and shortness of breath, 7% causes unconsciousness, 5% makes it difficult to breathe. At an oxygen concentration below 3%, a person will die within 1 minute. Previous experiments indicate that using the direct material burning of plywood, wood, and related materials inside a chamber and reducing oxygen to 15% concentrations, the growth of fire can be reduced significantly and humans will not be harmed (Hasegawa et al., 1986). It must be considered that decreasing the oxygen concentration increases the concentration of other gases such as nitrogen. In this study, the horizontal and vertical compartments were developed to explore the effect of orientation of cable fire growth rates under reduced oxygen concentrations.

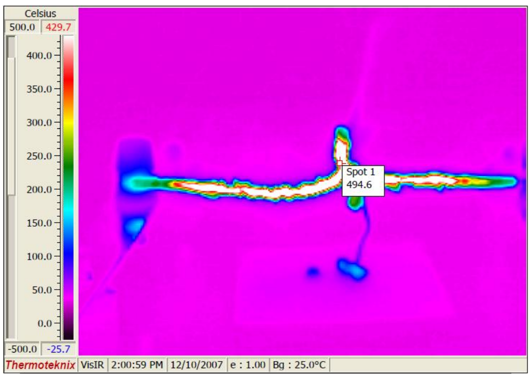
2. METHODOLOGY

In this study, a laboratory scale of experiment was developed and the direct measurement of the cable temperatures was conducted in specially designed compartment in open air and controlled atmospheric conditions.

2.1. Atmospheric Condition

Electrical currents flow inside an electrical conductor closely related to the heating it generates. Increasing the electrical conductor temperatures forms a pyrolisis process between it and the cable insulation, creating bubbles. If not controlled or eliminated by decreasing temperatures, these bubbles will burst. In overheated conditions, the PVC material of the cable insulation becomes fuel and the cable core represents heat source (Adrianus, 2007). Figures 1a and 1b show the processes of heating a cable in open atmospheric conditions.

(a)



(b)

Figure 1 (a) Cable under electrical overload; (b) Cable melted, damaged and smoldered

In controlled oxygen concentrations, the tested cable is located inside a glass or acrylic compartment, completed with adjusted holes for injecting or sucking oxygen, and installed with an infrared thermometer for data acquisition (Pangaribuan, 2007).

3. EXPERIMENT EQUIPMENT SET-UP

If the oxygen concentration increases, the flammability level will increase. Decreasing the oxygen concentration level could be dangerous for human life. By adjusting the oxygen concentration to between 15% and 19%, a designed test chamber can be made (Figure 2).

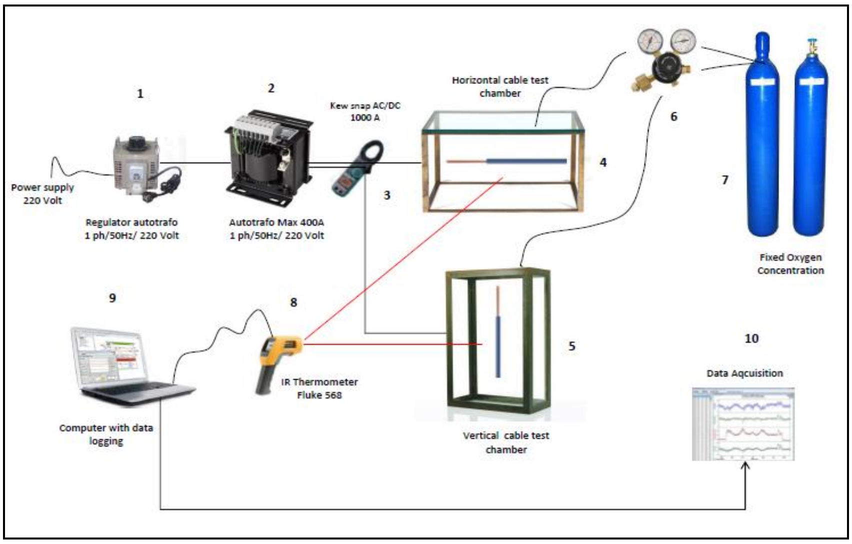


Figure 2 Experimental set-up

The experiment equipment consists of the following:

1 Autotrafo AC 220VAC/1ph/50Hz
2 Autotrafo 220VAC/1ph/ 400A/ 50Hz
3 Kew-snap AC/DC – 1000 A
4 Horizontal cable test chamber
5 Vertical cable test chamber
6 Oxygen regulator
7 Fixed oxygen concentration
8 IR Thermometer Fluke 568
9 Computer with acquisition software
10 Acquisition data result

(a) (b)

Figure 3 (a) Design of Cable test chamber view; (b) Design set-up ready for use

3.1. Experiment Procedures

A series of experiments were conducted with the oxygen concentration adjusted at 19%, 17%; 15% and 12%. The nominal electrical current (*In*) was the load and the electrical cable acted as the media where the electrical load will be flowed with electrical current according its amperes and nominal current to exceed its current carrying capacity. Changes to the electrical cable characteristics were be observed using an infra red (IR) thermometer by times, and will be recorded using data aqcuistion every 1 to 10 minutes. If a cable loaded with electric current under normal conditions does not affect the cable within 10 minutes, the cable will survive in unlimited amount of time. Under abnormal conditions, 10 minutes is more than enough to show changes or damage to the cable.

3.2. Experiment Process

The experiment started with oxygen concentrations at normal atmospheric conditions of 20.9%, which will be used as a reference. The oxygen concentration will be reduced gradually inside the testing chamber to 19%, 17%, 15%, and 12%. After the atmospheric condition, the cable will be loaded with electric current to 2x, 3x, and 4x its nominal current load capacity. For the test, the cable that will be used it is NYA type (PVC/SWA/PVC) with cross section of 1.5 mm^2.

4. RESULTS AND DISCUSSION

Although this series study the method of loading an electrical cable with electrical current in increments (nominal current, 2x, 3x, and 4x of nominal current), this discussion focuses on 3x and 4x only. This information is important because, when the cable is loaded with nominal current and 2x capacity, there is no significant phenomenon. Similar to electrical load, this study only evaluates the atmospheric conditions of 19%, 17%, and 15% oxygen concentration because studies have identified that there is no significant result when oxygen is controlled at 12% concentration.

4.1. Horizontal Orientation

4.1.1. Observation at atmospheric condition

When the cable is loaded with 3× the nominal electrical current (72 A), temperature generated is 84.75°C. In this condition, the cable smokes and starts to deform (the cable sags and white smoke is generated). This is understandable because the melting temperature of PVC insulation is 70°C.

When the cable is loaded with 4× its electrical current capacity, the temperature increases to 219.45°C. The cable insulation melts, the damaged metal conductor starts to smolder and, at the maximum temperature point, the cable breaks down. This gives an understanding of the principle of how the fuse works. The cable temperature starts at the same point – both 72 A and 96 A. When loaded with 3× the electrical load, the temperature increases over 70°C within 10 minutes with a maximum temperature of 169.12°C. As mentioned, if the cable is able to resist damage in this time, it will survive. If the cable damage and the observation stops after ten minutes, the data from this situation is compared to the controlled oxygen concentration.

When the cables are loaded with 4× its current capacity (96 A) the temperature on cable increases rapidly, reaching the peak temperature of 219.45°C. At this point, the copper material of the cable reaches its breaking capacity, which is dependent on the copper's thermal conductivity, resistance, and cross-section size, as shown by Equations 1 and 2. After it reaches its breaking temperature, the temperature decrease slowly back to the initial temperature. Although it is believed that the temperature in this condition will damage the cable when it is loaded with 4× the electrical current based on its capacity, this data is important as baseline when used for comparison data with the current capacity in the controlled oxygen concentration. This condition can be seen in Figure 4.

4.1.2. Observation at 19% oxygen concentration

When loaded with three times3x its nominal electrical current capacity, the maximum temperature of the cable were is 87.67^{o}C, which is and it was above the allowable PVC insulation temperature of 70°C. This compares to 84.75°C at atmospheric oxygen concentrations; the change in temperature (Δt) is 2.92°C when compared between atmospheric condition and at 19% oxygen concentration adjusted, relative there are no significant discrepancies, although in this condition the cable begins to smokes with this white smokes. At four times 4× of its ampicity current capacity, the temperature generated reaches a maximum of 146.22°C, at this condition the cable insulation melted, the cable damaged and its core has smoldered. This compares to atmospheric condition with generated temperature of 219°C; with the Δt is 73.23°C. This condition clearly giving shows significant differences, and this situation identifies that the controlled of oxygen concentration was is useful and works. This Δt is relatively wide Δt and its shows that the impact of the oxygen concentration affects the generated temperature generates in the cable.

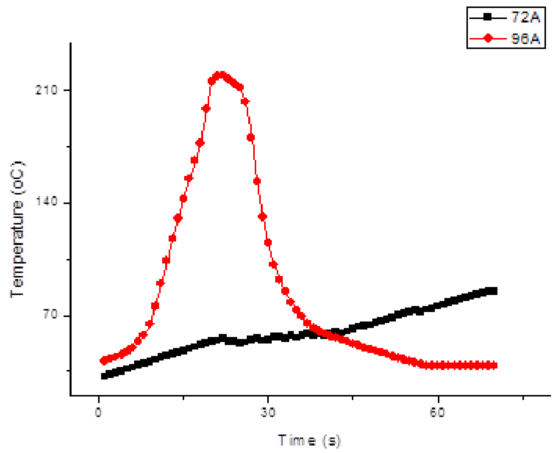


Figure 4 Cable loaded with 3&4 (72 and 96 ampere) nominal electrical nominal current

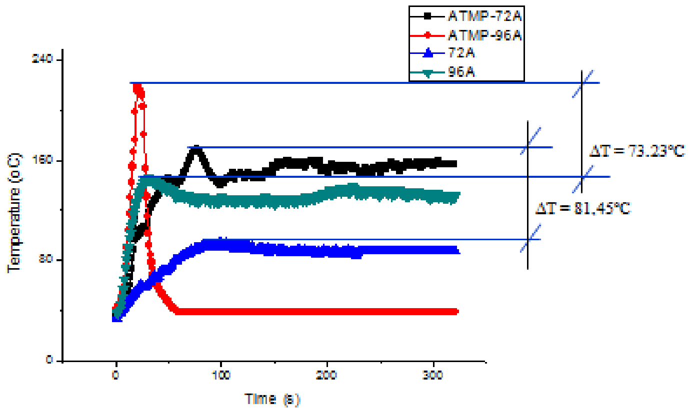


Figure 5 Comparison when cable loaded with 72 A and 96 A at atmospheric vs. oxygen concentration 19%

As shown in Figure 5, the identified temperature initiated the same baseline and gave almost the same pattern. When loaded with electrical current 3x its cable nominal current capacity, the temperature increased rapidly and reached its highest temperature at 87.67°C. After reaching the peak temperature, it decreased to 84.75°C and was then constant for more than 10 minutes. The same pattern using 4x the current capacity (96 A) was identified, the temperature increased rapidly until the peak temperature of 146.22°C, but did not rise above 150°C before the temperature decreased and became constant at 146.22°C.

When the temperature increased at 72 A and 96 A and the cable was heated, based on Equations 1 and 2, one can see the correlation that the electrical current depends on the temperature. When the temperature increased, the electrical resistant value will decrease; thus, when the peak temperature is reached, the electrical resistance increases and the electrical current decreases. Because of the decrease of electrical current, the temperature decreases before it reaches a constant of 84.75°C.

4.1.3. Observation at 17% oxygen concentration

When loaded with three times its nominal electrical current capacity, the maximum temperature of the cable was 53.30°C, which is under the allowable PVC insulation temperature of 70°C. This compares to 84.75°C at an atmospheric oxygen concentration of 19% with a Δt of 34.37°C between the atmospheric conditions and a Δt of 31.45°C at a 17% oxygen concentration. At four times of current load, the temperature generates the maximum temperature of 63.98°C; at this condition, the PVC cable insulation melted, the cable was damaged, and its core smoldered. This compares to atmospheric conditions in which the temperature generates 219.45°C and with oxygen concentration at 19% in which the temperature generates 146.22°C. The Δt is 167°C comparing the temperature generation with an oxygen concentration of 17% with atmospheric condition and a Δt of 93.77°C. This Δt is relatively wide and shows that the impact of the oxygen concentration affected the temperature.

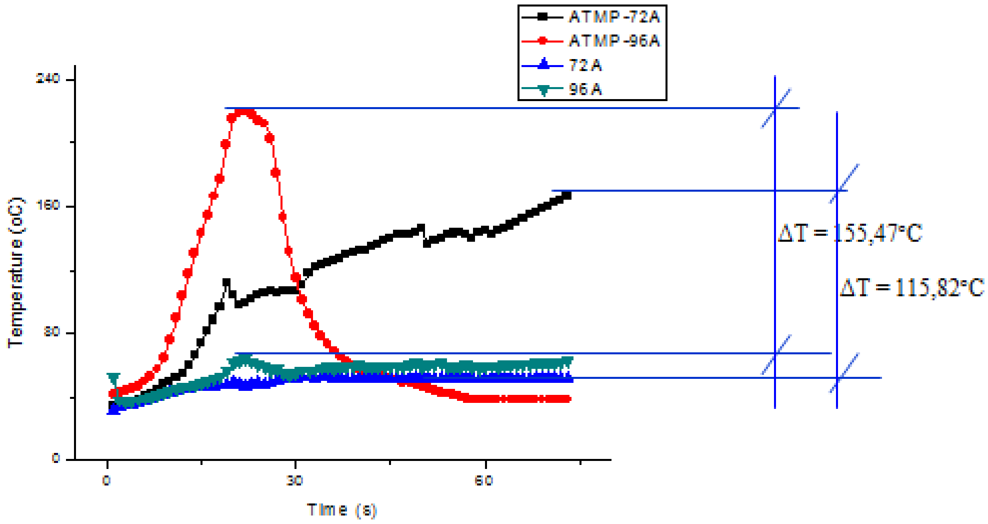


Figure 6 Comparison when cable loaded with 72 A and 96 A at atmospheric vs. oxygen concentration 17%

Figure 6 shows that controlling the oxygen concentration at 17% works properly. In both conditions (loaded with 72 A and 96 A), the generated temperatures are not over 70°C, which is the PVC melting temperature; although the temperature does not exceed 70°C, the cable's PVC insulation will damage and burn. When it is loaded with 96 A, the temperature increases but is kept under isolation allowable PVC melting temperature.

4.1.4. Observation at 15% oxygen concentration

When loaded with 3× its electric current capacity, the highest temperature generated was 101.63°C. At this condition, the cable insulation is damaged and there is thin white smoke due to this temperature over the allowable PVC insulation temperature. This compares to the temperature at the atmospheric oxygen concentration with the maximum temperature of 219.45°C with the 19% temperature of 87.67°C and 17% temperature of 53.30°C. The Δt is 117.82°C, 131.78°C, and 165.70°C, respectively. When at 4×, the cable temperature generates a maximum of 137.63°C and the insulation melted and was damaged, compared to an atmospheric temperature generation of 219.45°C, 146.22°C, and 52.45°C, with Δt of 81.82°C, 8.82°C, and 85.18°C identified with significant value.

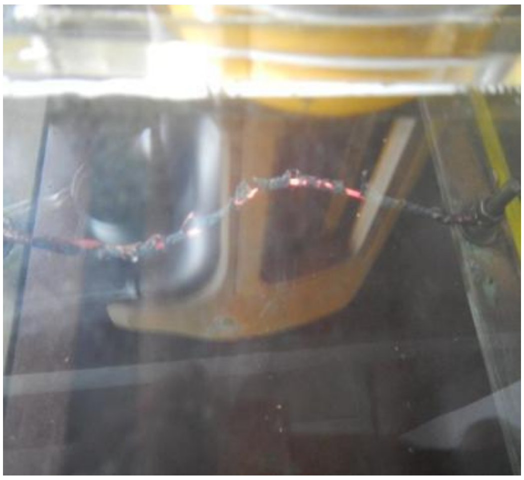


Figure 7 Cable glowing at oxygen concentration of 17% horizontal orientation

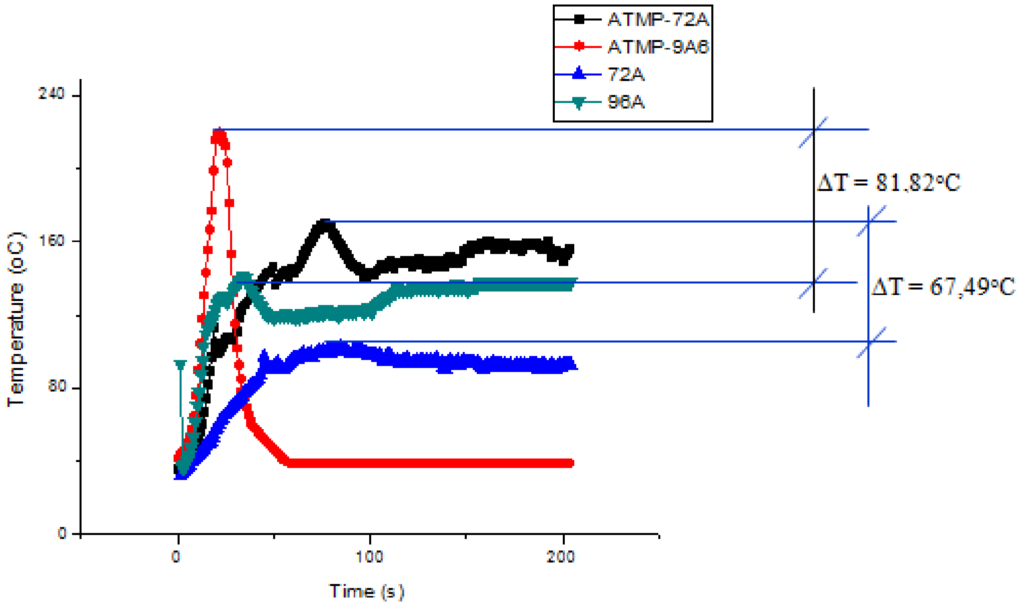


Figure 8 Comparison when cable loaded with 72 A and 96 A at atmospheric vs. oxygen concentration 15%

4.2. Effect of Temperature on Electrical Current at Adjusted Oxygen Concentration

4.2.1. Loaded with 48 A electrical current

When cable is loaded with 2× its nominal electrical current capacity (48 A) at a horizontal orientation, it is shown that the oxygen concentrations of 15%–19% force a decrease in the electrical cable's temperature and tend to give the same characteristics. Figure 9 shows that, when loaded with 2× the electrical current (48 A) and the oxygen concentration is adjusted to 19%, the Δt compared to the atmospheric condition is 28.92°C; at 17%, the Δt is 23.80°C; and at 15%, the Δt is 22.28°C.

4.2.2. Loaded with 72 A electrical current

When the cable is loaded with 3× its nominal electrical current capacity (72 A) at a horizontal and vertical cable orientation with oxygen concentrations of 15% and 19%, the oxygen concentration is reduced, giving it a significant value. Figure 10 shows that, when loaded with 2× the electrical current (72 A) and the oxygen concentration is adjusted to 19%, the Δt compared to the atmospheric condition is 104.49°C; at 17%, the Δt is 102.15°C; and at 15%, the Δt is 67.33°C.

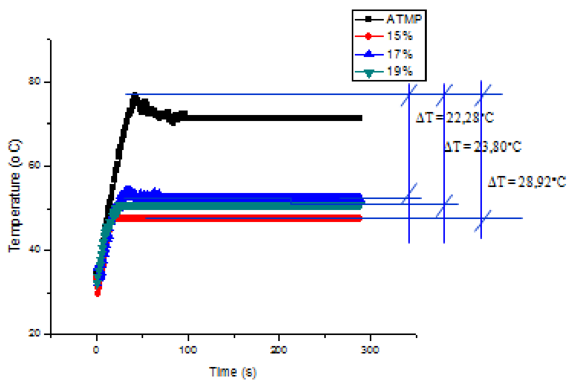


Figure 9 Comparing cable temperature at 48 A at asmopheric and oxygen concentartion 15%–19%

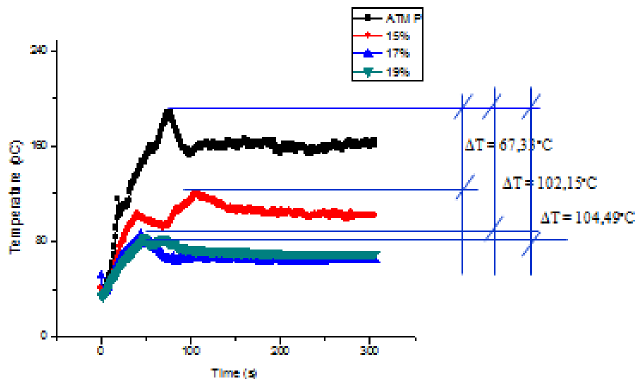


Figure 10 Comparing cable temperature at 72 A at atmospheric and oxygen concentration 15%–19%

4.2.3. Loaded with 96 A electrical current

When the cable is loaded with 4× its nominal electrical current capacity (96A) at a horizontal cable orientation with oxygen concentrations of 15%–19%, the oxygen concentration is reduced, giving a significant value. Figure 11 shows that, when loaded with 4× the electrical current (96 A) and the oxygen concentration is adjusted to 19%, the Δt compared to the atmospheric condition is 149.49°C; at 17%, the ΔT is 140.03°C; and at 15%, the Δt is 97.60°C.

Based on the series of curves identified when the temperature is increased, the electrical current flow inside the cable conductor will decrease gradually based on the electrical resistance and occurrence; instead, when the temperature decrease in the conductor, the temperature increases. These conditions occur in a quick, repeated succession, according to frequency. At the time, it looks out of control, but during this condition it reflects the characteristics of the metallic material being electrified. In this experiment, the electrical current is kept constant. In the future, research can be developed the same way but for the electrical compartment, where the environment has been saturated with flammable and/or combustible material – especially in gas environtments or hazardous area classifications.

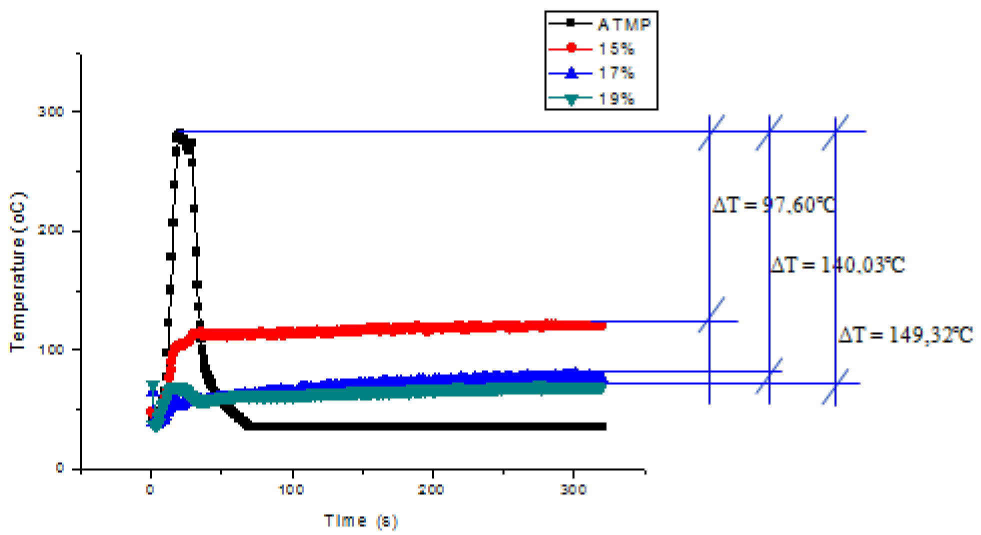


Figure 11 Comparing cable temperature at 96 A at asmopheric and oxygen concentration 15%–19%

5. CONCLUSION

Based on the experimental results, the following conclusions can be expressed: (1) with cable loads of 72 A and 96 A (3× and 4× of nominal current capacity cables) and when the concentration oxygen was adjusted to 19%, 17%, and 15%, the most affected oxygen concentration is 17%, with the highest Δt of 155.47°C; (2) when the cable was loaded with 48 A of electrical current at 17% oxygen concentration, the Δt is 28.92°C; at 72 A, the Δt is 104.49°C, and at 96 A, the Δt at 17% is 149.43°C; (3) when the load on the electrical cable exceeded its electric current capacity, the cable melted, was damaged, and smoldered, but the temperature remained below 70°C at a 17% oxygen concentration; thus, it was impossible to create an outbreak of fire and open flame.

6. ACKNOWLEDGMENT

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